NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 1069

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II. Redundant Versus Non-Redundant Color-Coding

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Naval Medical Research and Development Command
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15 January 1986

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William H. Rogers, M.A.
David F. Neri, LT, MSC, USNR

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NAVSUBMEDRSCHLAB

SUMMARY PAGE

PROBLEM

To determine the effects on search performance of color-coding symbols used in geographical situation (GEOSIT) displays. Both redundant color-coding (color redundant with shape) and non-redundant color-coding were tested.

FINDINGS

Both color-coding schemes resulted in significant reductions in search time and error rate for the color-coded threat information as compared to shape coding. Non-redundant color-coding, however, also resulted in a significant enhancement of performance for the non-color-coded platform information. Response times were significantly lower for the Surface category than for either the Airborne or Submerged categories.

APPLICATION

This study, in conjunction with our first study of color-coding of GEOSIT displays, proves that the application of color can significantly improve performance on these displays. In addition, it has been shown that redundant color-coding may not be as advantageous to performance as non-redundant color-coding.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command Work Unit M0100.001-1022--"Enhanced performance with visual sonar displays". This report was submitted for review on 27 September 1985, approved for publication on 15 January 1986, and designated as NSMRL Report No. 1069.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

The effect on search time of redundant versus non-redundant color-coding of symbols in geographical situational (GEOSIT) displays was evaluated using 36 observers who were randomly assigned to three coding schemes: monochrome-coding, redundant color-coding, and non-redundant color-coding. In the color-coding schemes, only the threat information (Friendly, Unknown, and Hostile) was color coded, either redundantly with shape or not. The platform information (Submerged, Surface, and Airborne) was coded by shape in all three coding schemes.

Performance when searching for the color-coded threat target categories was enhanced by over 100% compared to monochrome shape-coding. In addition, response time on the non-color-coded platform categories was significantly faster under the non-redundant color-coding scheme than under the redundant color-coding scheme.

The importance of using color in visual displays has been well documented in the past several years (1-3). Many studies have shown that color-coding information in these displays enhances performance in numerous types of tasks (4-6). The application of color, however, is not always advantageous (7) and has actually been shown to interfere with performance in some cases (8). Consequently, it becomes essential to investigate the use of color in a systematic fashion and not merely assume that the addition of color will always enhance performance.

One possible use of color is to encode categorical information presented visually in tactical displays such as Geographical Situation (GEOSIT) displays. Information about three levels of threat (Friendly, Unknown, and Hostile) and three types of platform (Submerged, Surface, and Airborne) are now coded by the shape of symbols used in these displays, but with the advent of reliable color monitors, the appication of color-coding to these displays has become feasible. In fact, some countries, such as France, are already reported to be regularly using color in these types of displays. Observers using GEOSIT displays perform search and counting tasks that are quite similar to classical search and counting tasks in which color has been shown to have an enhancing effect (9-11). Hence, it is assumed that the addition of color to these displays will enhance performance.

In a recent study (12) we evaluated the application of redundant color to encode information about contacts in a GEOSIT display. We decided that using nine colors to redundantly encode the nine types of contacts, resulting from the combination of three threat levels and three platform types, would clutter this type of display, and hence we color-coded only the threat information which is arguably the more important. Hence, only three colors were employed in the color-coding scheme; the threat information was redundantly color-coded with shape while the platform information was coded solely in terms of shape. Color-coding of the threat information enhanced search and counting performance for the three threat target categories by over 100%, without any significant effect on the non-color-coded platform target categories.

Is it possible to develop a coding scheme in which search time performance on the platform categories, as well as the threat categories is enhanced? There are a number of possible solutions. One is to risk the problem of clutter and increase the number of colors to nine. Another alternative is to redundantly encode the platform information with another feature such as brightness or saturation. This option is currently under consideration in our laboratory. A third alternative is to simplify the coding scheme so that the threat information is only color-coded and the platform information is only shape-coded. Removing the redundancy for the threat information may actually make the task easier, because it may be easier to locate symbols that vary only in color (as in the case with non-redundant color-coding) than to locate symbols that vary in both shape and color (as is the case with redundant color-coding). For example, when color is used to redundantly encode the threat information, observers are required to locate three colors and three different shapes when they search for a particular category of contact platform. Hence, they might have to locate all instances of blue semi-circles, red semi-squares, and yellow arrow heads with this coding scheme. However, with non-redundant color-coding, observers searching for the same category of contact platform would only have to locate three colors of the same shape; for example, blue, red, and yellow semi-circles. Intuitively, the latter task would seem to be much easier.

Many people fear that if information is coded only by color, operators would be hopelessly lost if one of the electron guns failed or the shadow mask became damaged. This fear may become groundless, however, as color monitors become more reliable. Hence it was decided to test a coding scheme in which color was not redundant.

The present study extended the findings of our previous experiment by comparing the effect on response time of redundant color-coding, non-redundant color-coding, and monochrome-coding in a GEOSIT display.

METHOD

Subjects

A total of 36 Navy personnel participated as voluntary observers. All had normal color vision as determined by the American Optical Society's Hardy-Rand-Rittler Pseudoisochromatic Plates. Those who normally wore corrective lenses did so during the experiment.

Apparatus

Simulated GEOSIT displays were presented on an Advanced Electronics Design Model 512 Color Graphics and Imaging Terminal, driven by a Digital PDP 11/04 laboratory computer.

Observers were seated approximately 50 cm from the terminal screen that was placed at eye level. Responses were recorded via a panel with four microswitches mounted in a square pattern and wired to the computer. A fluorescent light, situated above and behind the observer, cast 2.7 Lux of illumination on the CRT screen. This is the highest amount of light typically found illuminating control consoles in submarine sonar shacks under operational conditions (13). A Kodak Carousel 800 projector was used to present slides on a white cardboard screen during an initial training phase.

Stimuli

There were 16 simulated GEOSIT displays which differed only in the distribution of contact symbols presented in the four quadrants of each display. All had the same fictitious land and sea map, with the land outlined in green. Each display was divided into four quadrants with a white cross hair.

There were three color-coding conditions, monochrome, redundant color-coding, and non-redundant color-coding. In each coding scheme, each contact was coded for type of platform (Surface, Airborne, Submerged) and threat level (Friendly, Unknown, Hostile). In the monochrome and redundant color conditions, both classes of information were encoded by shape. In the redundant condition, threat level was also encoded by color, using cyan, red, and yellow. In the non-redundant color condition, threat information was encoded only by these colors, while type of platform was encoded only by shape, using circles and semi-circles.

Each of the nine types of contact symbols (three platforms x three threat levels) was presented in four different locations, resulting in 36 contact symbols in each display. The locations were random except for these constraints: there were always nine contact symbols in each quadrant, they could not overlap each other or the cross hairs, and, of course, only the Airborne contact symbols could appear over land.

In each display, the quadrant that contained a plurality of a given type of target category was designed as the "target" quadrant, for which the observer was instructed to search. The target category was defined by either type of platform or threat level, but never both: observers, for example, were never asked to search for "Friendly Airborne" contacts, but might be asked to search for all instances of the "Friendly" category or the "Airborne" category.

The displays had quadrants with both low and high "target" category densities. A low target density quadrant was one in which there were only one or two more targets than any other quadrant; a high target density quadrant had at least four (but no more than eight) more targets than any other quadrant. Hence, in low target density quadrants, few of the targets were clustered together, while in high target density quandrants many of the targets were clustered together.

Each display could be used in more than one condition. The same display might be used for a low target density Airborne display with quadrant one as the target quadrant and as a high target density Submerged display with quadrant three as the target quadrant.

Procedure

The testing was preceded by a training session in which the observers learned the symbols employed in the experiment. Each of the 36 observers was randomly assigned to one of the three coding conditions: monochrome shape-coding, redundant color-coding, or non-redundant color-coding. During the training, each observer was first shown a picture of the nine symbols in the coding scheme along with their meanings and the scheme was described by the experimenter. Following this, slides of the symbols by themselves were presented one at a time to the observer. Each symbol was presented randomly four times to the observer; he was asked to name each one and was told if he was correct. As in our initial study, by the end of the training, all of the observers could easily name each of the nine contact symbols with no errors.

Following the training, the observer's choice reaction times to a single stimulus presented on the CRT screen in each of the four quadrants were measured. One-half second after an auditory warning signal, a small white circle appeared randomly in one of the quadrants. The observer responded as quickly as possible by pressing the appropriate button on the response panel, each one corresponding to one of the quadrants. The circle then disappeared, and a new trial was begun one second later. The computer recorded each reaction time and whether or not the response was correct. Trials continued until there were 30 correct responses to each quadrant.

After this session, the observer was shown a sample display and asked to point to quadrants that contained the most of several categories of contacts that were defined by the experimenter. This ensured that the observer understood the task.

In the actual experiment, each observer was told what target category to look for in a given set of trials. The sea and land masses of the display were then drawn by the computer, and, after a warning signal, the 36 contact symbols appeared simultaneously. The observer searched for the quadrant which contained the most of the target category and pressed the corresponding button on the response panel as quickly as possible without sacrificing accuracy. The computer recorded the reaction time of the response and its correctness.

The order of presentation of the six target categories (three threat levels and three types of platforms) was the same for each of the three coding conditions; it was counterbalanced such that two observers in each condition started with a different target category. In addition, each target category occupied each presentation position an equal number of times. There were eight sequential trials for each target category, a total of 48 trials in each coding condition. The density (high or low) in the target quadrants was completely randomized within the eight trials for a target category block, with four low and four high target density target quadrants. The four presentations of each density allowed the "target qudrants" to be counterbalanced across the quadrants. This resulted in 48 trials per observer. The entire session, including training, took approximately 30 minutes.

RESULTS

Only the times for correct responses were analyzed. Data points for incorrect responses were estimated from that individual's cell mean. The choice reaction time to each quadrant, obtained in the initial session with the small white circles, was subtracted from the total response time for each trial. These corrected response times (RTs) thus represented each observer's time to locate the target quadrant without regard for the time required simply to respond to each particular quadrant. The RT, averaged across the four quadrants, was then obtained for each of the six target categories under each density condition, resulting in a total of 12 scores for each observer. These RTs, averaged across observers, are given in Table I.

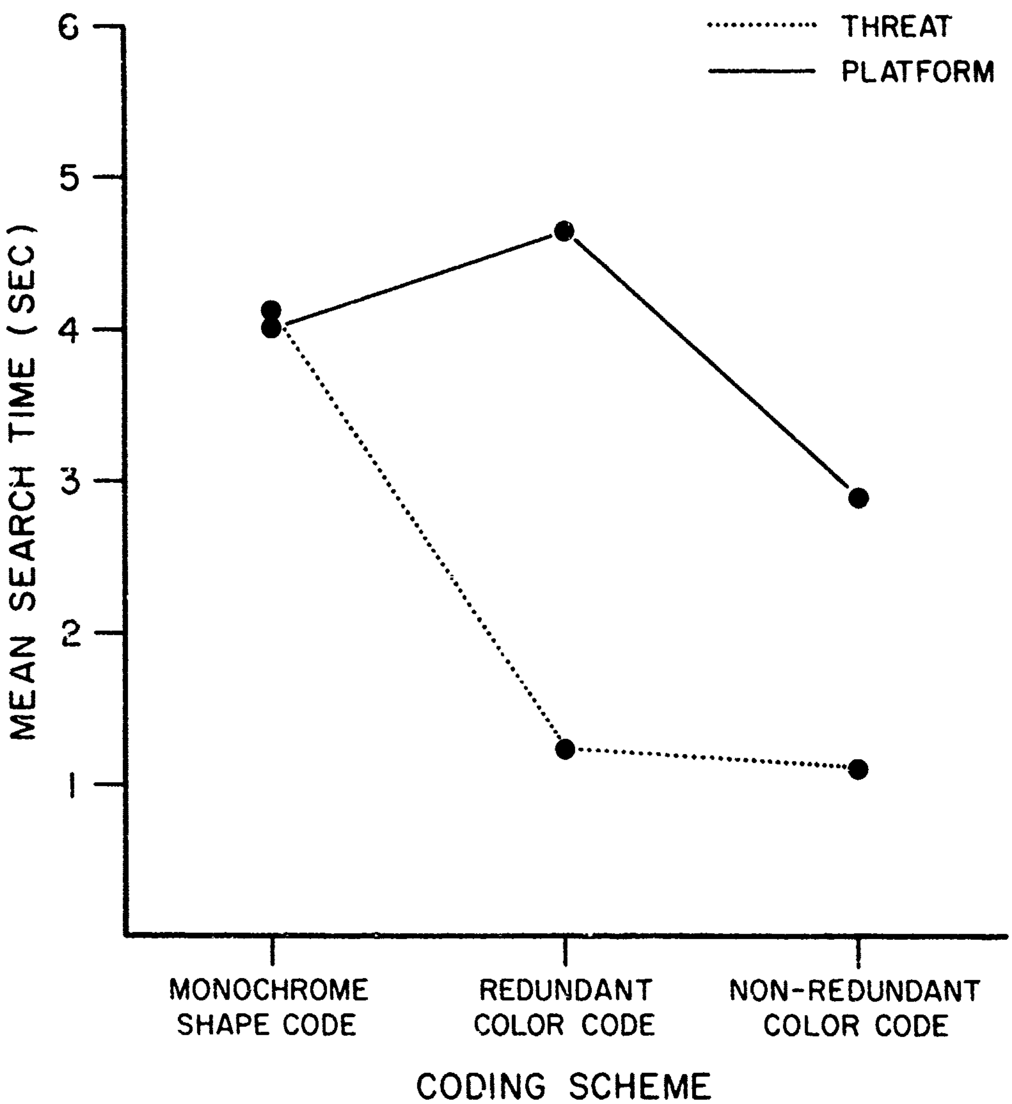

Fig. 1. Mean corrected response times for the two target classes (threat vs. platform collapsed across contacts) by coding scheme interaction collapsed across target density conditions.

TABLE I. MEAN CORRECTED RESPONSE TIMES (SECONDS) FOR THE SIX TARGET CATEGORIES AND TWO TARGET DENSITIES UNDER THE THREE CODING SCHEMES.

CODING SCHEME	TARGET DENSITY	TARGET CATEGORY AIR	SUB	SURF	FRND	UNKN	HOST
MONOCHROME SHAPE-CODING	LOW	5.37	5.61	3.43	4.10	5.15	5.36
	HIGH	4.18	3.44	1.94	2.61	3.87	3.51
REDUNDANT COLOR-CODING	LOW	6.29	6.41	4.37	1.62	1.56	2.09
	HIGH	4.48	3.65	2.61	0.65	0.70	0.66
NON-REDUNDANT COLOR-CODING	LOW	4.19	4.31	2.62	1.55	1.30	1.85
	HIGH	2.79	1.98	1.41	0.60	0.66	0.58

Effect of Color-Coding on the Two Classes of Information

RT was significantly affected by an interaction between Coding Scheme and Target Class ($F(2,33)=24.59$; $p<.01$) as is shown in Figure 1. As can be clearly seen, there was a significant decrease in RT to the threat targets when that information was color-coded ($p<.01$). Under both color-codes, RT to the threat targets was significantly faster than RT to the platform targets ($p<.01$). Another important result was that RT to the non-color-coded platform targets was significantly faster with non-redundant color-coding than with redundant color-coding ($p<.05$). Newman Keuls means tests for the differences among the three coding schemes are summarized in the appendix.

Effect of Color-Coding on the Individual Target Categories

Figure 2 shows the effect of color-coding on the six individual target categories in which there was a significant interaction between Coding Scheme and Target Category ($F(10,165)=12.06$; $p<.01$).

Color-coding of the Friendly, Unknown, and Hostile categories resulted in significant reductions in RT ($F(2,198)=6.25$, 14.87, and 12.33, respectively; $p<.01$) as can easily be seen in Figure 2. Both color-codes significantly reduced RT for the three color-coded threat

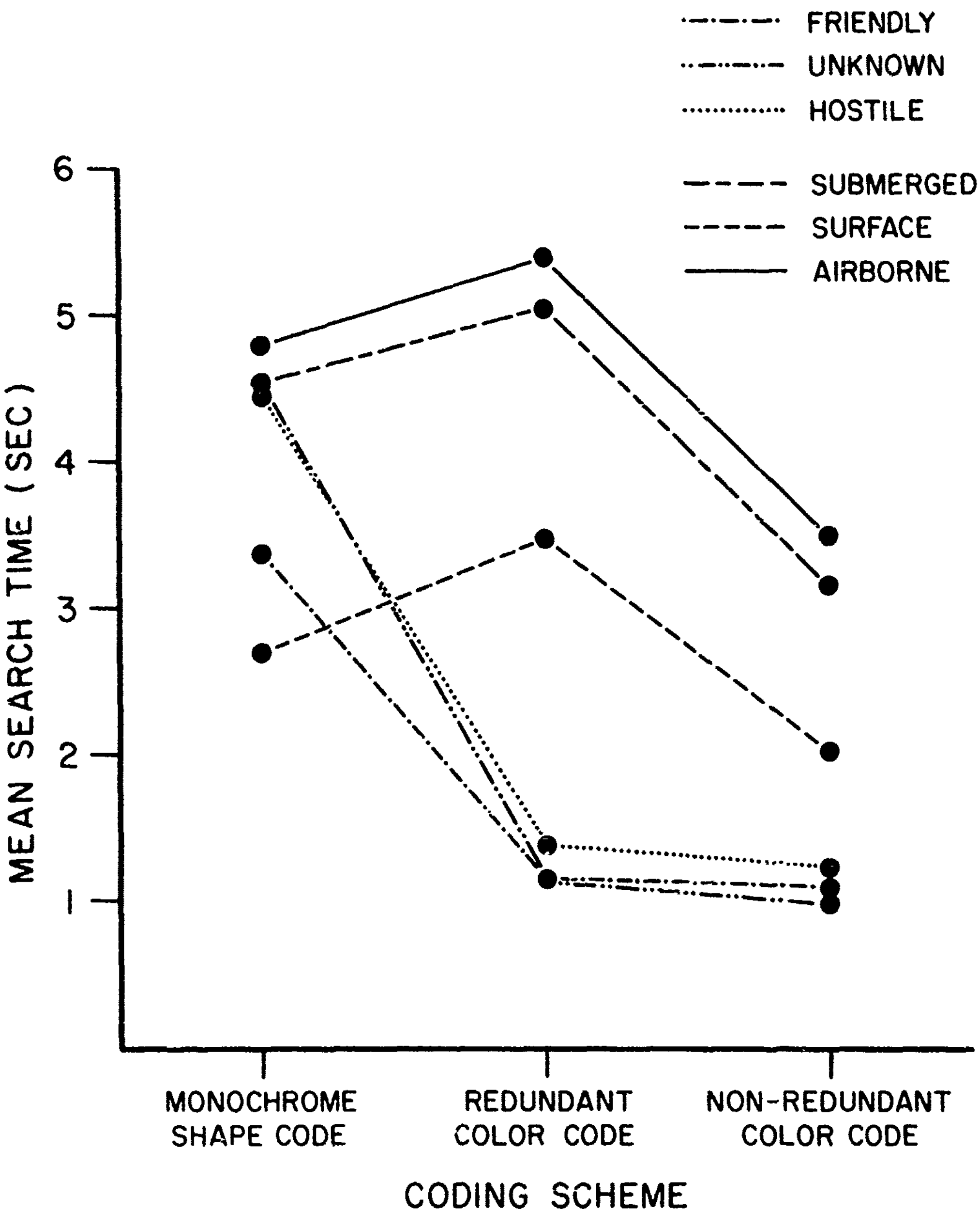

Fig. 2. Mean corrected response times for the target category by coding scheme interaction collapsed across target density conditions.

categories compared to the monochrome shape-coding as verified by Newman-Keuls means tests ($p<.01$ for all three categories).

Coding scheme also had a significant effect on two of the three platform categories, Airborne and Submerged, even though these were not color-coded ($F(2,198)=3.47$ and 3.57, respectively; $p<.05$). With both categories, RT was significantly reduced with non-redundant color-coding as compared to redundant color-coding ($p<.05$). Although the same trend was observed for the Surface category, the difference did not reach statistical significance even at the $p<.10$ level.

It is also clear from observing Figure 2 that there were significant differences among the six target categories under each particular coding scheme ($F(5,165)=8.28$ (monchrome), 47.19 (redundant color), and 14.48 (non-redundant color); $p<.01$). Under monochrome shape-coding, the Surface category yielded significantly faster RTs than all of the other categories ($p<.01$). In addition, the Friendly category yielded a significantly faster RT than the Airborne category ($p<.05$).

Under both redundant and non-redundant color-coding, it is clear that all three color-coded threat categories yielded faster RTs than the three non-color-coded platform categories. In addition, however, the Surface category yielded a significantly faster RT than the other two platform categories ($p<.01$).

The most important effects of applying color were that color-coding of the threat information significantly reduced RT to the threat categories. In addition, the RTs to the non-color-coded platform categories were significantly reduced with non-redundant color-coding, as compared to redundant color-coding. All of the Newman-Keuls means tests for the Coding Scheme by Target Category interaction are summarized in the appendix.

Effect of Target Density

As can be seen in Figure 3, RT was also significantly affected by an interaction between Target Density and Target Category ($F(5,165)=7.09$; $p<.01$). The overriding main effect of target density is evident in that for all six target categories, RT was faster under high target density than under low target density ($p<.01$). As can be seen from Figure 3, under low target density, the three threat categories, as well as the Surface category, all yielded

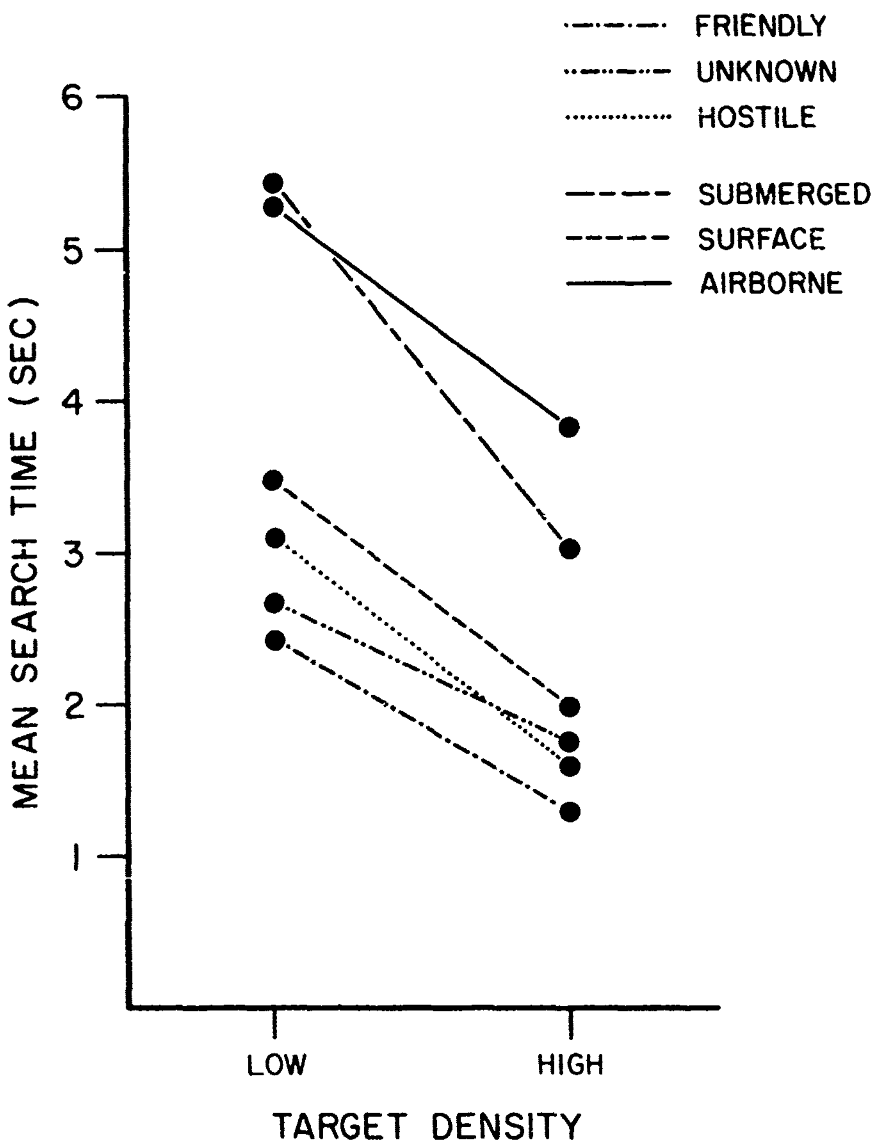

Fig. 3. Mean corrected response times for the target category by target density conditions collapsed across coding schemes.

significantly faster RTs than the Submerged and Airborne categories. The same was true for the high target density, except, in this condition the Submerged category also yielded significantly faster RTs than the Airborne category. Summaries of the Newman-Keuls means tests for these data are given in the appendix.

Error Rates

Error rates were fairly low, 7.3% with non-redundant color-coding, 9.0% with redundant color-coding and 12.7% with no color-coding, and were, therefore, not analyzed statistically. Target density had a very strong effect on error rate. Of a total of 167 errors, 89% were made in the low target density condition. Since few errors were made in the high target density condition, both density conditions were combined in Fig. 4 which shows the total number of errors made with each target category and coding scheme. The most errors were made searching for Airborne and Submerged targets, the two categories that also gave the slowest RTs. Both color coding schemes reduced the errors made while searching for the three threat targets, but only the non-redundant color-coding also reduced errors while searching for the Airborne and Submerged targets.

DISCUSSION

The most significant finding was that non-redundant color-coding of the threat information significantly reduced the RTs and error rates on the non-color-coded platform target categories compared to redundant color-coding. Apparently, non-redundant color-coding did, in fact, simplify the task more than redundant color-coding. One possible drawback regarding non-redundant color-coding is the reliablity of color monitors relative to monochrome monitors. As color monitors become as reliable as monochrome monitors, non-redundant color-coding will definitely represent a means of simplifying data presentation in visual displays. For example, it is commonly anticipated that within several years chromatic flat panel displays will be equal in resolution to current chromatic CRT monitors. Until then, designers will have to weigh the benefits and costs of non-redundant versus redundant color-coding of information.

Several other effects on the non-color-coded platform categories are important to point out. First, although there was no statistical difference between the RTs obtained for the platform targets under monochrome shape-coding versus redundant color-coding, RT did increase somewhat with

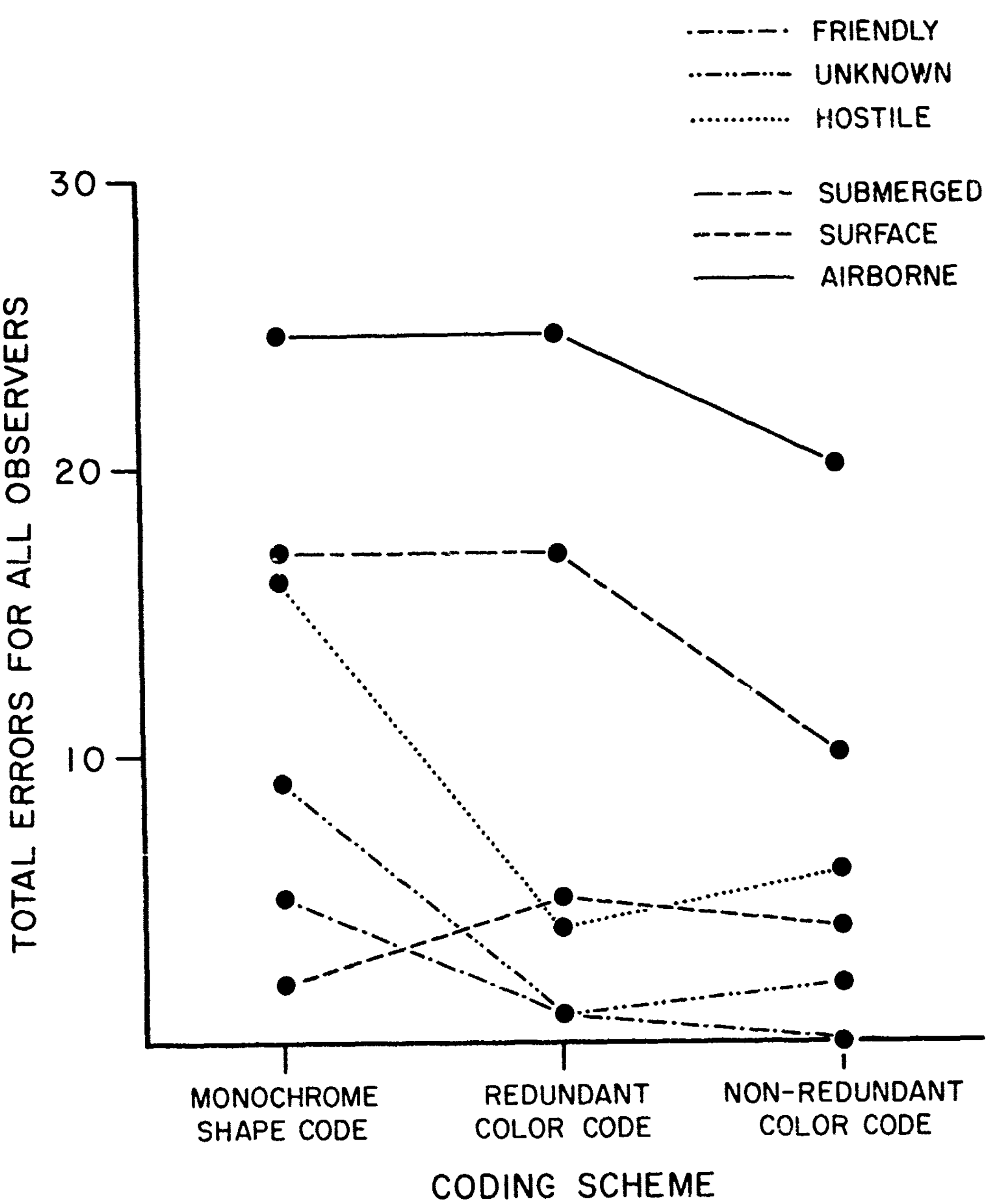

Fig. 4. Total number of errors committed by all observers for the six target categories under the three coding schemes summed across the two target densities.

the latter, as compared to the former coding scheme. Although the effect was not statistically significant, this same trend was also found in our initial study (12). Consequently, the interference effect of color-coded information on non-color-coded information mentioned by Luder and Barber (8) may be relevant but only to a very small degree. The fact that error rate for the Airborne and Submerged categories was the same under both monochrome shape-coding and redundant color-coding further indicates that the interference effect of color on non-color-coded information is minimal on this task.

It is also noteworthy that non-redundant color-coding resulted in faster RTs to the platform categories than did monochrome-coding (Table I and Figure 2), although only the RTs to the Submerged targets were significantly different. Consequently, non-redundant color-coding has been shown to yield better performance than either shape-coding or non-redundant color-coding, even on non-color-coded information.

The second most significant finding of this study was that both color-coding schemes dramatically reduced the RTs for the color-coded threat targets, relative to shape-coding, replicating the findings of the first study. This is of particular significance, because the two procedures were somewhat different. In the first study, all observers were trained and tested under all coding schemes, whereas in the second study each observer was trained and tested under only one coding scheme. Hence color-coding is effective whether it is the only coding scheme one learns or whether it is learned subsequent to another coding scheme. These findings are also supported by the results of a study by Kopala (14) in which redundant color-coding of threat information was found to improve both response time and error rate compared to shape-coding. In her study, only threat information was encoded, however, so no effect of color-coding on non-color-coded information could be measured.

The reductions in RT under both color-coding schemes were not due to the acceptance of a higher error rate. Very often in RT experiments, a reduced RT is caused by what is commonly referred to as a speed-accuracy trade-off (15). This was certainly not the case in the present study, where in almost all cases a low RT was accompanied by a low error rate. The converse was also true: the highest RTs and the highest error rates were found for the Airborne and Submerged categories.

RT was almost twice as fast to Surface targets as to Airborne and Submerged targets. This was found in both studies and for all coding schemes and both target densities. It is obvious that the symbols used for the Surface targets are much easier to locate than the other platform symbols. This difference was probably due to the shape and size of the symbols. In fact, the Surface symbol was twice the size of the other two platform symbols. It might be worth some effort to devise symbols for encoding the Airborne and Submerged categories that are easier to identify.

Target density also had a strong effect on RT; the high condition yielded much faster times than the low. This is easily understandable; the high target density quadrants were more different from other quadrants than were the low target density quadrants.

This study and our initial report provide clear evidence that color, applied to GEOSIT displays, can dramatically enhance performance. They also demonstrate that non-redundant color-coding is better than redundant color-coding for this type of search task. One must, however, weigh the benefits of color-coding that is not redundant with some other feature, such as shape, against the costs. Finally, there should be a study to see if performance on the platform categories is improved if they are coded redundantly with another feature such as brightness or saturation.

REFERENCES

1. Christ, R.E. (1975). Review and analysis of color coding research for visual displays. Human Factors, 17, 542-570.

2. Cook, T.C. (1974). Color coding: A review of the literature. Aberdeen, MD: Technical Note 9-74, U.S. Army Human Engineering Laboratory, Aberdeen Proving Grounds (AD/A-001/555).

3. Laycock, J. (1982). Recommended colours for use on airborne displays. Farnborough, Hants: Royal Aircraft Establishment, Technical Report 82110 (AD A129243).

4. Barker, E. & Krebs, M.J. (1977). Color coding effects on human performance, an annotated bibliography. Arlington, VA: Office of Naval Research, ONR-CR213-136-1F (AD/A039318).

5. Hoops, H. (1980). The advantage of the color-code modality versus alphanumeric- and symbol-code. Monterey, CA: Naval Postgraduate School (AD/A084383).

6. Silverstein, L.D. & Merrifield, R.M. (1982). The development and evaluation of color display systems for airborne applications. Atlanta, GA: General Physics Corporation.

7. Neri, D.F. & Zannelli, D. (1984). Guidelines for the use of color in SUBACS A displays. Groton, CT: Naval Submarine Medical Research Laboratory/Naval Underwater Systems Center Joint Research Report No. 1032.

8. Luder, C.B. & Barber, P.J. (1984). Redundant color coding on airborne CRT displays. Human Factors, 26(1), 19-32.

9. Cahill, M. & Carter, R.C. (1976). Color code size for searching displays of different density. Human Factors, 18(3), 273-280.

10. Carter, R.C. (1982). Visual search with color. Journal of Experimental Psychology: Human Perception and Performance, 8(1), 127-136.

11. Green, B.F. & Anderson, L.K. (1956). Color coding in a visual search task. Journal of Experimental Psychology, 51(1), 19-24.

12. Jacobsen, A.R., Neri. D.F., & Rogers, W. (1985). The effects of color-coding in GEOSIT displays. I. Color as a redundant code. Groton, CT: Naval Submarine Medical Research Laboratory Research Report 1061.

13. Kinney, J.A.S., Luria, S.M., Neri, D.F., Kindness, S.W., & Schlichting, C. (1981). Surveys of lighting and working conditions in submarine sonar shacks. Groton, CT: Naval Submarine Medical Research Laboratory Research Report No. 955.

14. Kopala, C.J. (1979). The use of color-coded symbols in a highly dense situation display. Proceedings of the Human Factors Society, 23rd Annual Meeting, 397-401.

15. Swensson, R.G. (1972). The elusive tradeoff: Speed vs accuracy in visual discrimination tasks. Perception and Psychophysics, 12, 16-32.

APPENDIX

TABLE II. NEWMAN KEULS MEANS TEST FOR DIFFERENCES AMONG THE THREE CODING SCHEMES FOR EACH OF THE TWO TARGET CLASSES. CODES ARE PRESENTED IN ORDER OF FASTEST TO SLOWEST RT FROM TOP TO BOTTOM AND FROM LEFT TO RIGHT. THE NUMBERS REPRESENT THE DIFFERENCE IN SECONDS BETWEEN THE TWO CORRESPONDING CODING SCHEMES (*=p<.05, **=p<.01).

A. THREAT CATEGORIES

	REDUNDANT	MONOCHROME
NON-REDUNDANT	0.12	3.01 **
REDUNDANT		2.89 **

B. PLATFORM CATEGORIES

	MONOCHROME	REDUNDANT
NON-REDUNDANT	1.11	1.75 *
MONOCHROME		0.64

TABLE III. SUMMARY OF NEWMAN KEULS MEANS TESTS ON DIFFERENCES AMONG THE THREE CODING SCHEMES FOR EACH OF THE SIX TARGET CATEGORIES. NUMBERS REPRESENT THE DIFFERENCE IN RT (SEC) BETWEEN THE TWO CORRESPONDING CODING SCHEMES WHICH ARE LISTED IN ORDER OF INCREASING RT FROM TOP TO BOTTOM AND FROM LEFT TO RIGHT (*=p<.05, **=p<.01).

A. AIRBORNE CATEGORY

	MONOCHROME	REDUNDANT
NON-REDUNDANT	1.28	1.89 *
MONOCHROME		0.61

B. SURFACE CATEGORY

	MONOCHROME	REDUNDANT
NON-REDUNDANT	0.68	1.48
MONOCHROME		0.80

C. SUBMERGED CATEGORY

	MONOCHROME	REDUNDANT
NON-REDUNDANT	1.38	1.89 *
MONOCHROME		0.51

D. FRIENDLY CATEGORY

	REDUNDANT	MONOCHROME
NON-REDUNDANT	0.06	2.27 **
REDUNDANT		2.21 **

E. UNKNOWN CATEGORY

	REDUNDANT	MONOCHROME
NON-REDUNDANT	0.15	3.53 **
REDUNDANT		3.38 **

F. HOSTILE CATEGORY

	REDUNDANT	MONOCHROME
NON-REDUNDANT	0.15	3.22 **
REDUNDANT		3.07 **

TABLE IV. SUMMARY OF NEWMAN-KEULS MEANS TESTS FOR DIFFERENCES AMONG THE SIX TARGET CATEGORIES FOR EACH OF THE THREE CODING SCHEMES. NUMBERS REPRESENT THE DIFFERENCE IN RT (SEC) BETWEEN THE TWO CORRESPONDING CATEGORIES. THE CATEGORIES ARE LISTED IN ORDER OF INCREASING RT FROM LEFT TO RIGHT AND FROM TOP TO BOTTOM (*=p<.05, **=p<.01).

A. MONOCHROME SHAPE-CODING

	FRIENDLY	HOSTILE	UNKNOWN	SUBMERGED	AIRBORNE
SURFACE	0.86*	1.75**	1.82**	1.83**	2.08**
FRIENDLY		0.89	0.96	0.97	1.22*
HOSTILE			0.07	0.08	0.33
UNKNOWN				0.01	0.26
SUBMERGED					0.25

B. REDUNDANT COLOR-CODING

	FRIENDLY	HOSTILE	SURFACE	SUBMERGED	AIRBORNE
UNKNOWN	0.01	0.24	2.36**	3.90**	4.25**
FRIENDLY		0.23	2.35**	3.89**	4.24**
HOSTILE			2.12**	3.66**	4.01**
SURFACE				1.54**	1.89**
SUBMERGED					0.35

C. NON-REDUNDANT COLOR-CODING

	FRIENDLY	HOSTILE	SURFACE	SUBMERGED	AIRBORNE
UNKNOWN	0.10	0.24	1.03*	2.16**	2.51**
FRIENDLY		0.14	0.93*	2.06**	2.41**
HOSTILE			0.79	1.92**	2.27**
SURFACE				1.13**	1.48**
SUBMERGED					0.35

TABLE V. SUMMARY OF NEWMAN-KEULS MEANS TESTS ON THE DIFFERENECES AMONG THE SIX TARGET CATEGORIES FOR EACH OF THE TWO TARGET DENSITIES. THE NUMBERS REPRESENT THE DIFFERENCE IN RT (SEC) BETWEEN THE TWO CORRESPONDING CATEGORIES THAT ARE LISTED IN ORDER OF INCREASING RT FROM TOP TO BOTTOM AND FROM RIGHT TO LEFT (*=p<.Ø5, **=p<.Ø1).

A. LOW TARGET DENSITY

	UNKN	HOST	SURF	AIR	SUB
FRND	Ø.25	Ø.68 *	1.Ø5 **	2.86 **	3.Ø2 **
UNKN		Ø.43	Ø.8Ø **	2.61 **	2.77 **
HOST			Ø.37	2.18 **	2.34 **
SURF				1.81 **	1.97 **
AIR					Ø.16

B. HIGH TARGET DENSITY

	HOST	UNKN	SURF	SUB	AIR
FRND	Ø.29	Ø.45	Ø.69 *	1.73 **	2.53 **
HOST		Ø.16	Ø.4Ø	1.44 **	2.24 **
UNKN			Ø.24	1.28 **	2.Ø8 **
SURF				1.Ø4 **	1.84 **
SUB					Ø.8Ø **

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER NSMRL Report No. 1069	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE EFFECTS OF COLOR-CODING IN GEOSIT DISPLAYS. II. REDUNDANT VERSUS NON-REDUNDANT COLOR-CODING		5. TYPE OF REPORT & PERIOD COVERED Interim Report 6. PERFORMING ORG. REPORT NUMBER NSMRL Rep. No. 1069
7. AUTHOR(s) A. R. Jacobsen , W. H. Rogers, D. F. Neri		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, Connecticut 06349-5900		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 65856N M0100.001-1022
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, Connecticut 06349-5900		12. REPORT DATE 15 Jan 1986 13. NUMBER OF PAGES 20
14 MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Medical Research and Development Command Naval Medical Command, National Capital Region Bethesda, Maryland 20814		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16 DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

color coding; tactical displays; search time

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effect of search time on redundant versus non-redundant color-coding of symbols in geographical situational (GEOSIT) displays was evaluated using 36 observers who were randomly assigned to three coding schemes: monochrome-coding, redundant color-coding, and non-redundant color-coding. In the color-coding schemes, only the threat information (Friendly, Unknown, and Hostile) was color coded, either redundantly with shape or not. The platform information (Submerged, Surface, and Airborne) was coded by shape in all three coding schemes.

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S/N 0102-014-6601

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20. cont'd

Performance when searching for the color-coded threat target categories was enhanced by over 100% compared to monochrome shape-coding. In addition, response time on the non-color-coded platform categories was significantly faster under the non-redundant color-coding scheme than under the redundant color-coding scheme.